Improving geomechanical knowledge to have a better assessment of the hydraulic erodibility of rock

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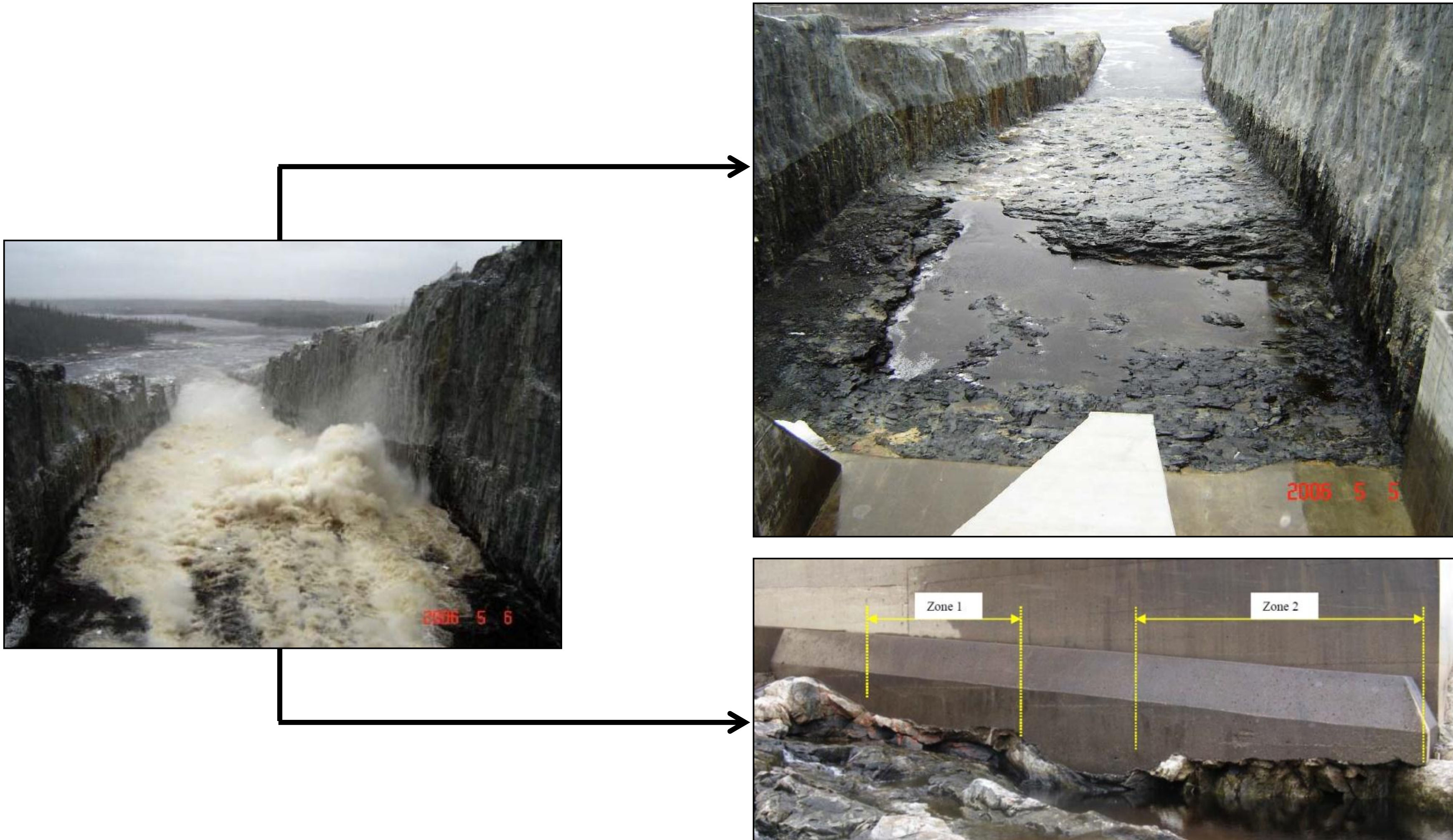
PLAN

1. Project context
2. Research orientation
3. Issues
4. Goals
5. Results
6. Conclusion

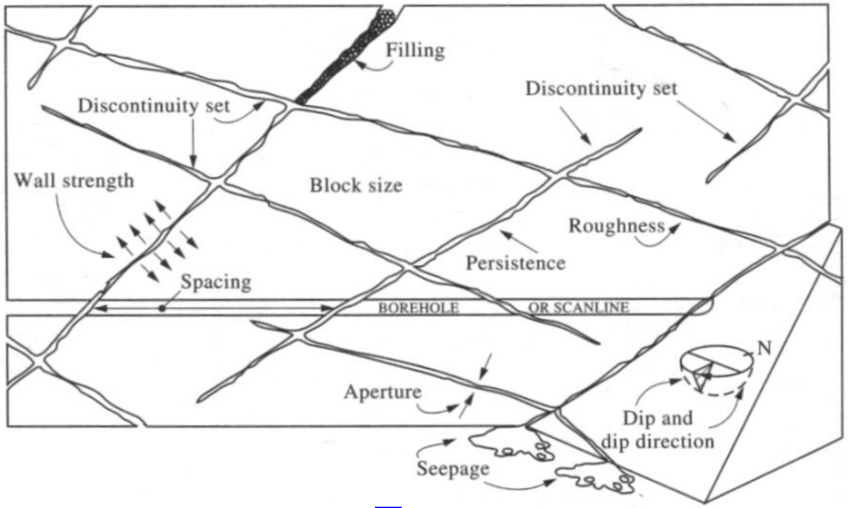
PROJECT CONTEXT



RESEARCH ORIENTATION

Rock resistance

Hydraulic stream power



Kirsten's Index (1982)

Available hydraulic stream power

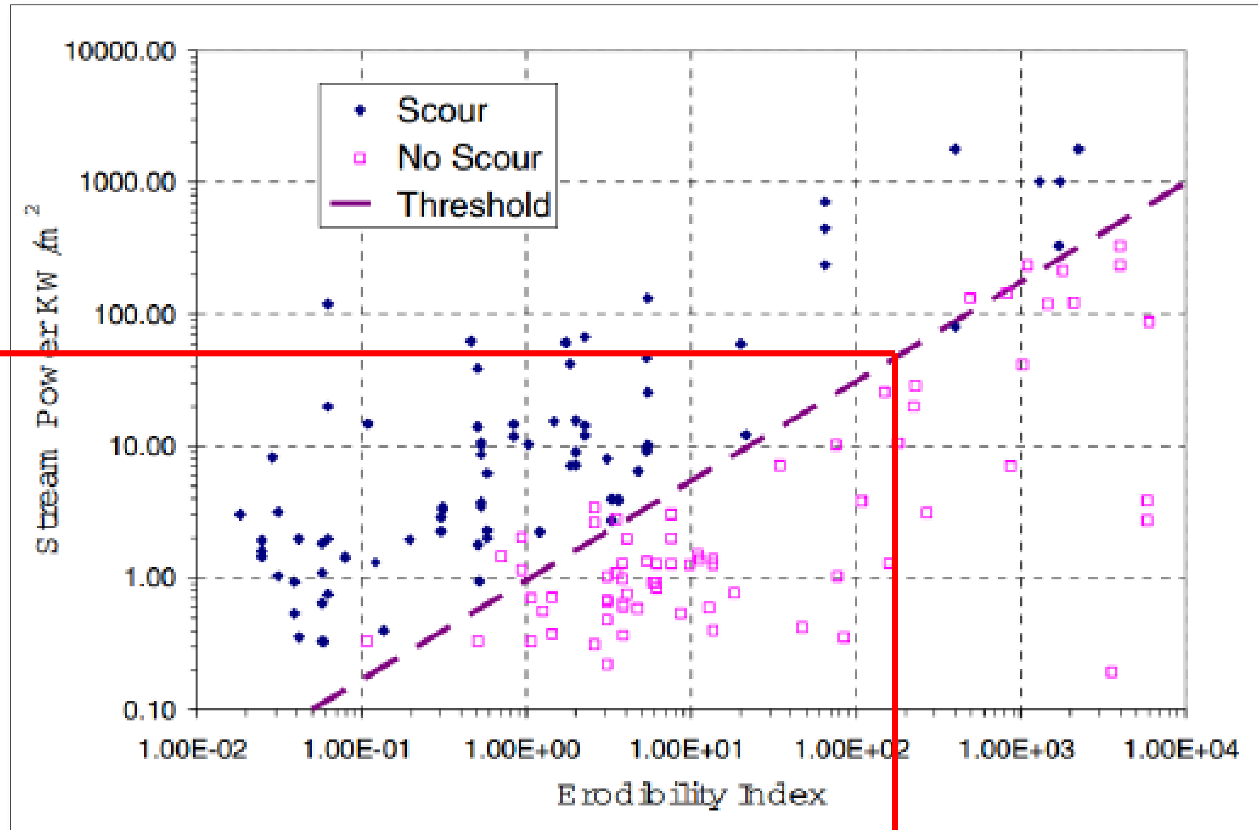
RESEARCH ORIENTATION

$$N = M_s \times K_b \times K_d \times J_s$$

		Rating
M_s : Compressive Strength of Intact Rock	→	0.87 - 280
K_b : Rock Block Size (RQD/Jn)	→	1 - 100
K_d : Discontinuities Shear Strength (Jr/Ja)	→	0.03 - 5.33
J_s : Relative Ground Structure	→	0.37 - 1.5

RESEARCH ORIENTATION

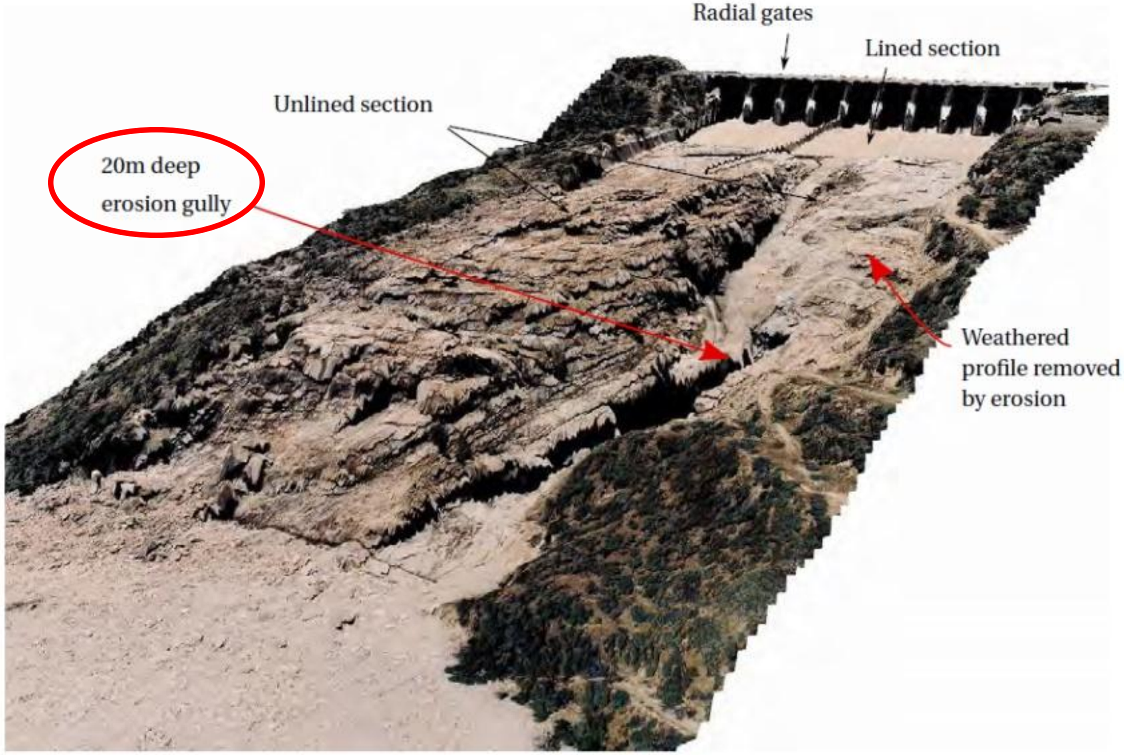
Required hydraulic stream power



Annandale, 1995

Kirsten's Index

RESEARCH ORIENTATION



Example of erosion at Copeton dam, Australia

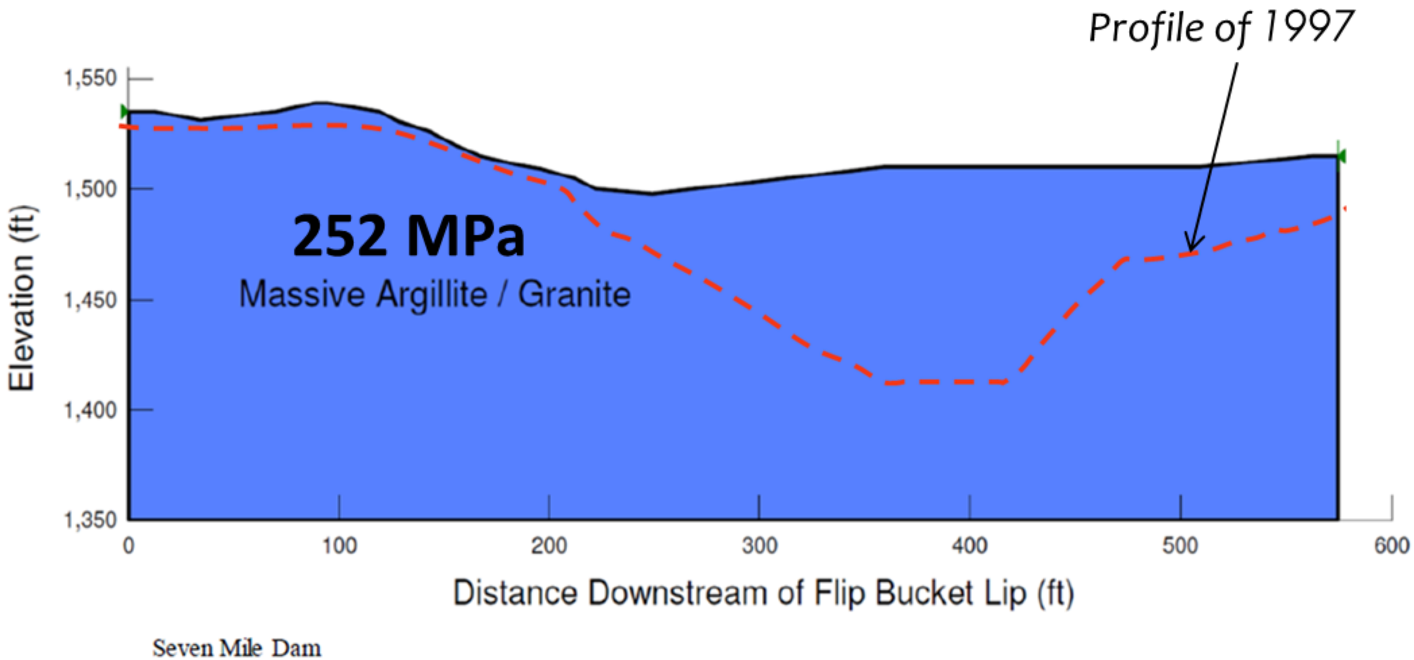
Pells, 2016

<u>Required</u> hydraulic stream power = 476 kW/m²
<u>Available</u> hydraulic stream power = 74 kW/m²

→ ***What we can do ?***

ISSUE

1. Compressive Strength of Intact Rock (Ms)



Modified from Rock (2015)

ISSUE

1. Compressive Strength of Intact Rock (Ms)

The strength of the rock-mass is mostly controlled by its defects (Joints). So, it can be considered that rock substance strength plays a very limited, if not negligible role, in the erodibility of fractured rock-masses.

Pells, 2016

eGSI → *Hoek 's Chart(2006)*

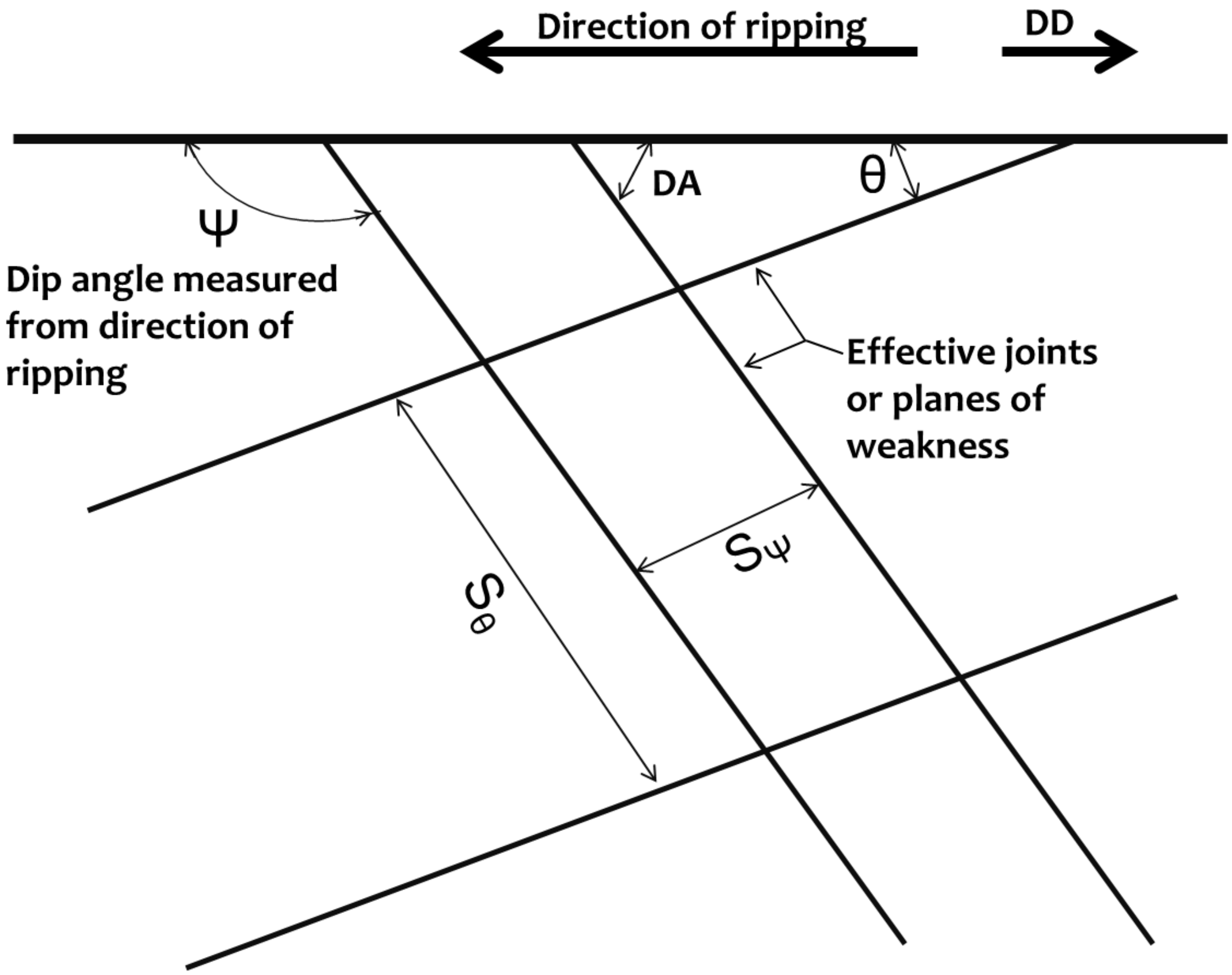
RMEI

↓

Nature of the defects	Very rough surfaces, eg JRC ≥ 12	Rough surfaces, e.g. JRC 8-10	Slightly rough surfaces e.g. JRC 4-8	Smooth surfaces e.g. JRC < 4	Smooth or slickensided surfaces
	No separation	Apperture < 1mm	Apperture 1-2mm	Apperture 2 to 5mm	Apperture > 5mm
	UCS > 50MPa	UCS 20MPa to 50 MPa	UCS 5MPa to 20MPa	UCS 1MPa to 5MPa	UCS < 1MPa, or Soft gouge > 5mm thick

ISSUE

2. Relative Ground Structure (Js)



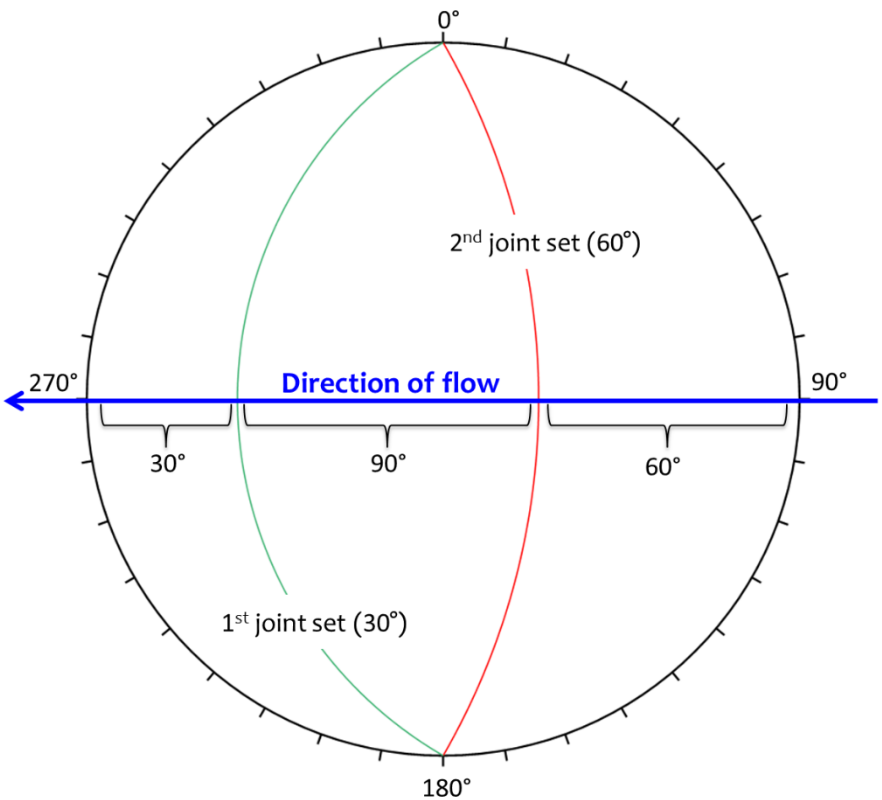
Kirsten (1982)

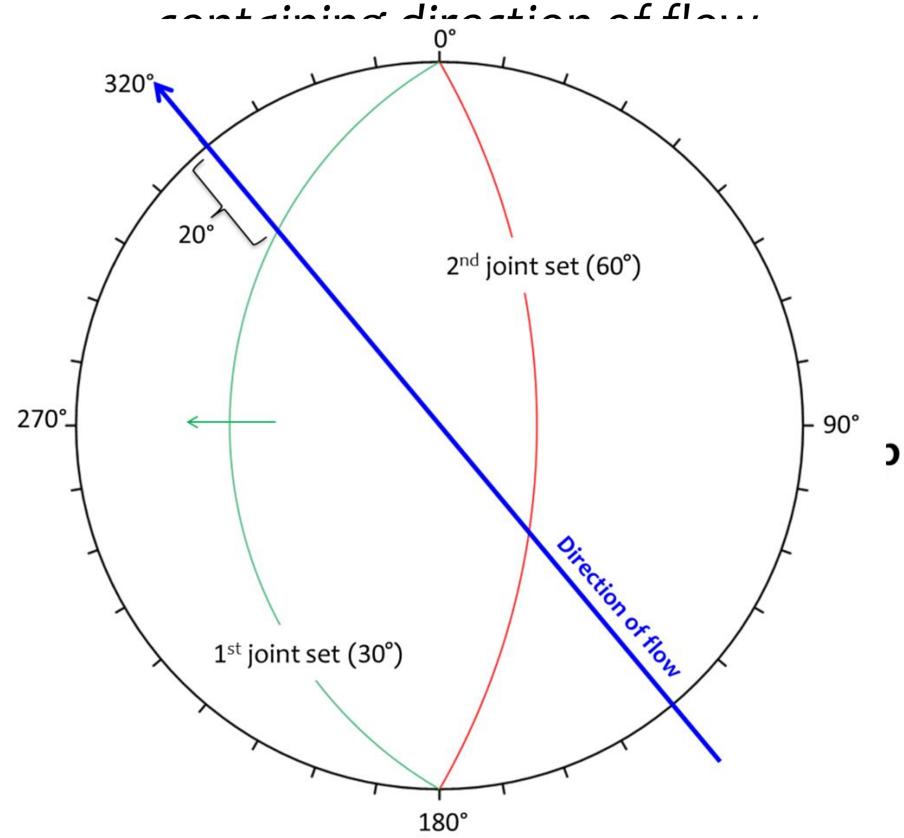
Orthogonal Fractured System

ISSUE

2. Relative Ground Structure (Js)

Apparent dip angle of closer
spaced joint set in vertical plane



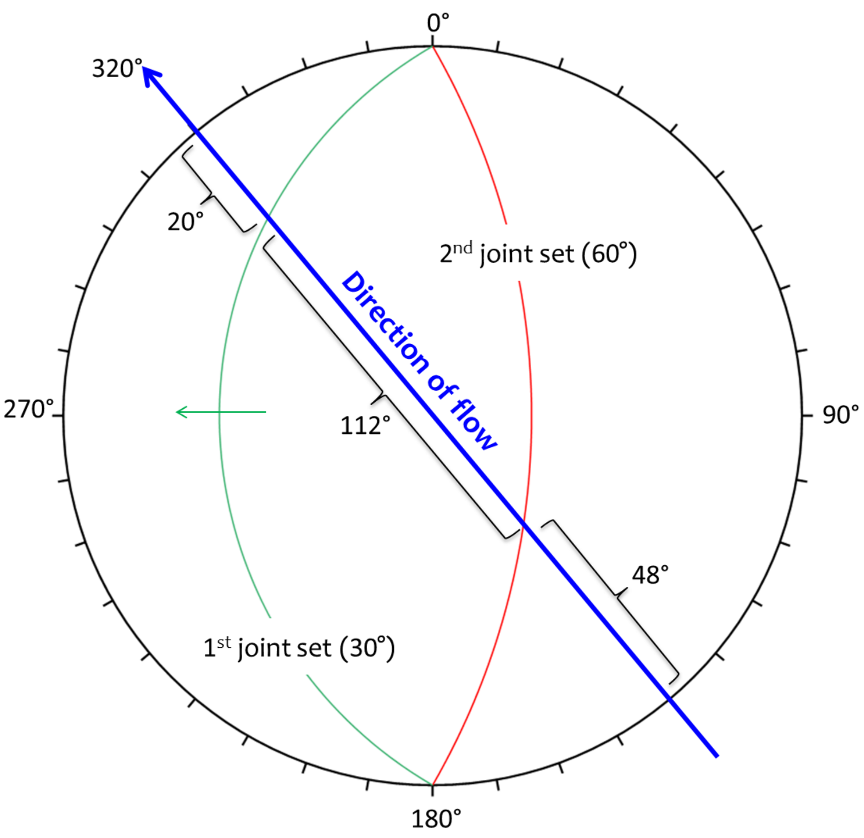


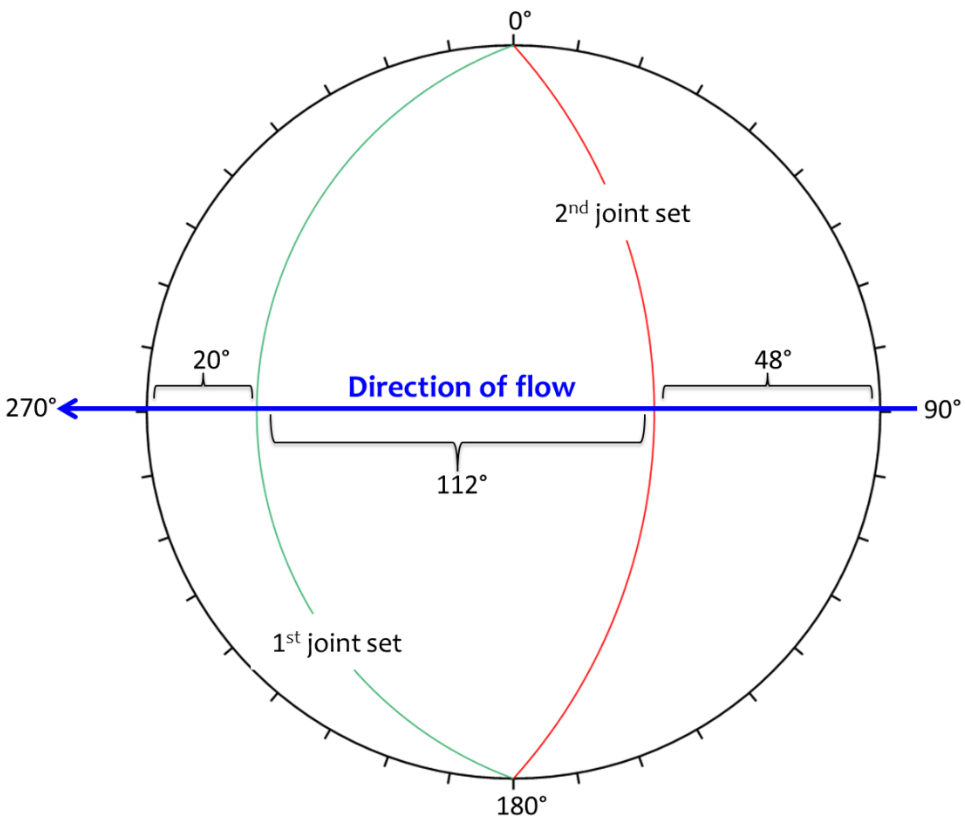
Perpendicular Flow

Non-Perpendicular Flow

ISSUE

2. Relative Ground Structure (Js)





Non-Perpendicular Flow

Non-Orthogonal Fractured System

GOALS

- ***Evaluation of the effect of the compressive strength of intact rock***

- ***Evaluation of the relative ground structure for :***
  - ***Non-Perpendicular Flow***
  - ***Non-Orthogonal Fractured System***

RESULTS

1. Evaluation of the effect of the compressive strength of intact rock

Classification of rock-mass according to Kirsten's index

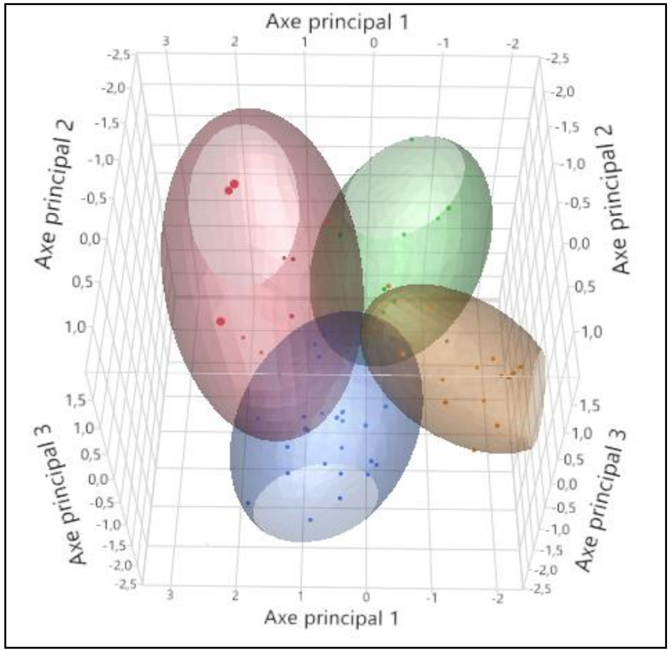
Class	Index N	Excavatability	Erodibility
4	1.00 - 9.99	Easy ripping	Easy erodible
5	10.0 - 99.9	Hard ripping	Hard erodible
6	100 - 999	Very hard ripping	Very hard erodible
7	1 000 - 9 999	Extremely hard ripping	Extremely hard erodible
8	> 10 000	Balsting	Very Extrem. hard erodible

Performing a sensitivity analysis to verify if the M_s can affect the shifting-up of rock mass erodibility class.

RESULTS

1. Evaluation of the effect of the compressive strength of intact rock

Clusters in 3D



Boumaiza et al. (2017)

Averages values of factors

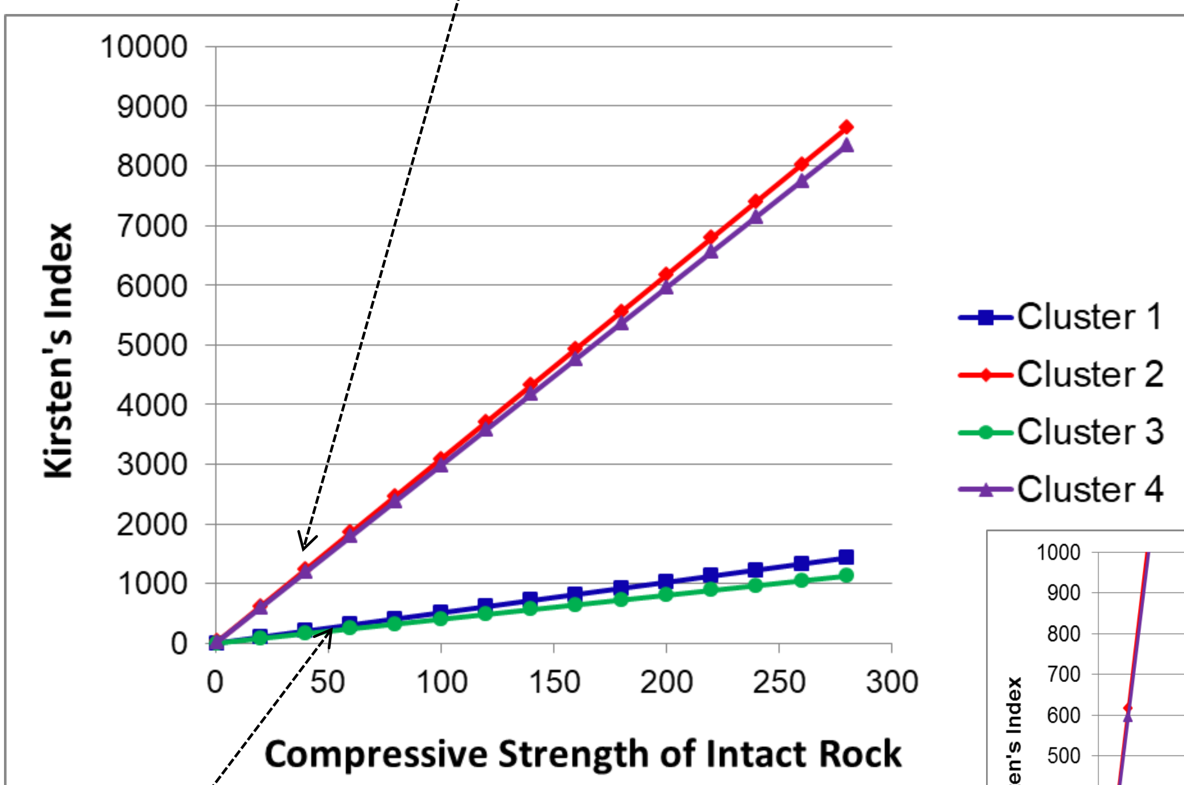
Cluster	K_b	K_d	J_s
1	14.47	0.68	0.52
2	25.45	1.25	0.97
3	6.87	0.58	1.01
4	17.20	2.25	0.77

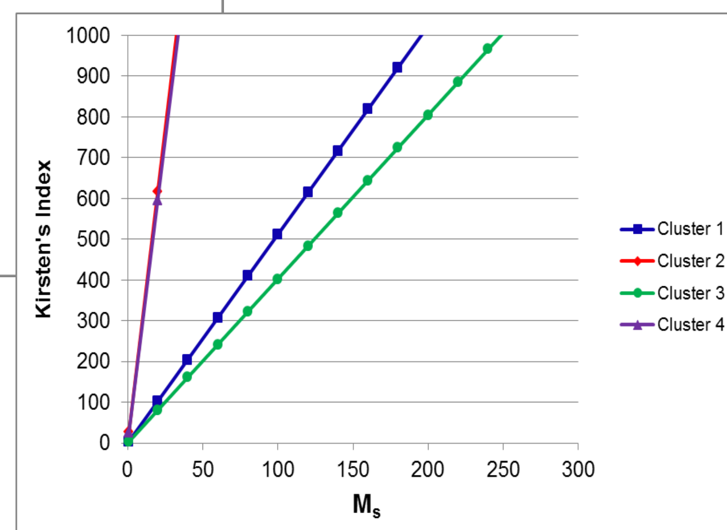
M_s is varying from 0.87 to 280

RESULTS

1. Evaluation of the effect of the compressive strength of intact rock

M_s is above **50** MPa : ***N*** is situated in the Class **7** (1000 to 10 000)





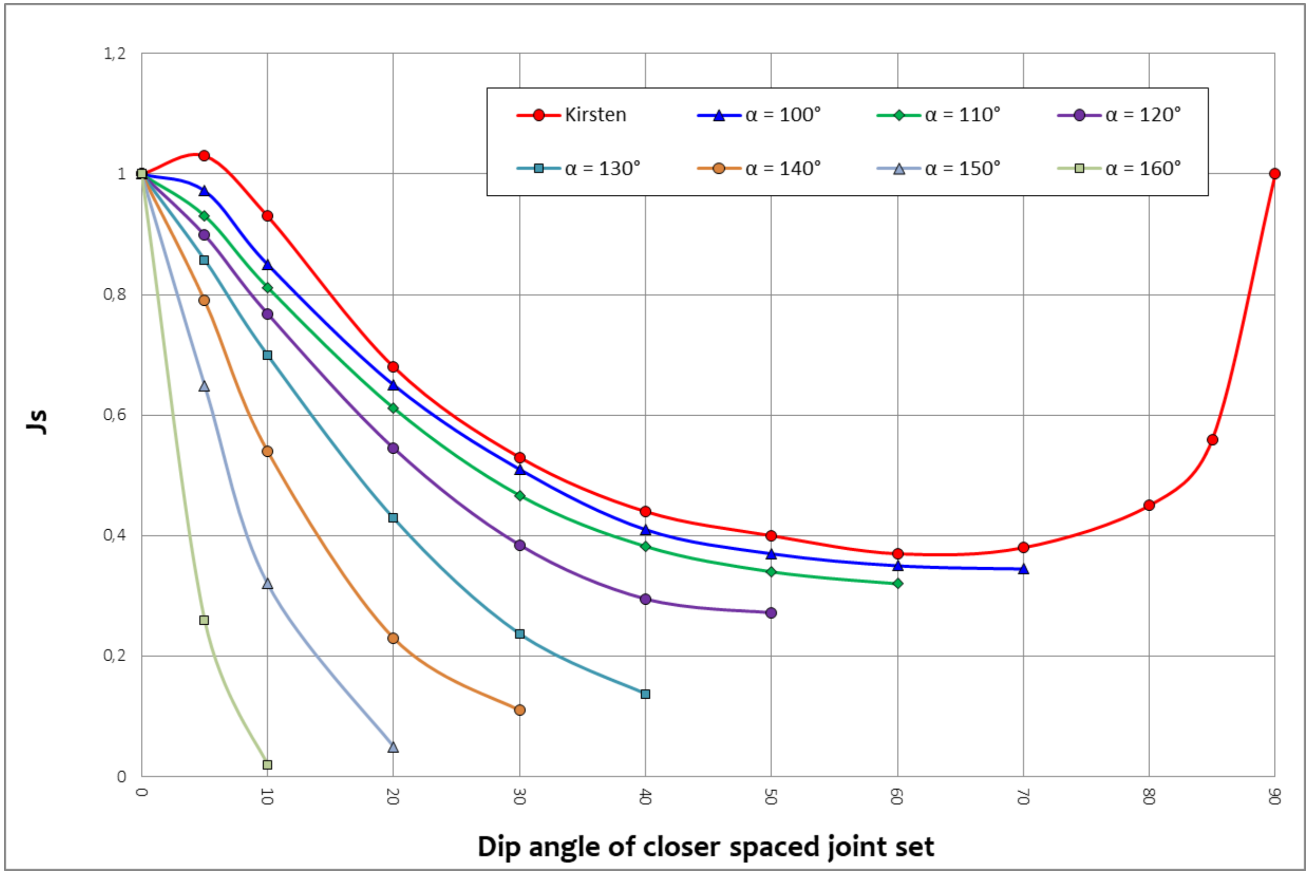
M_s is above **50** MPa : ***N*** is situated in the Class **6** (100 to 1000)

RESULTS

2. Evaluation of the relative ground structure for Non-orthogonal fractured system

- **Equation 1**: is applied when the blocks are oriented in the direction of flow
- **Equation 2**: is applied when the blocks are oriented against the direction of flow

α angle > 90°
RJS = 8

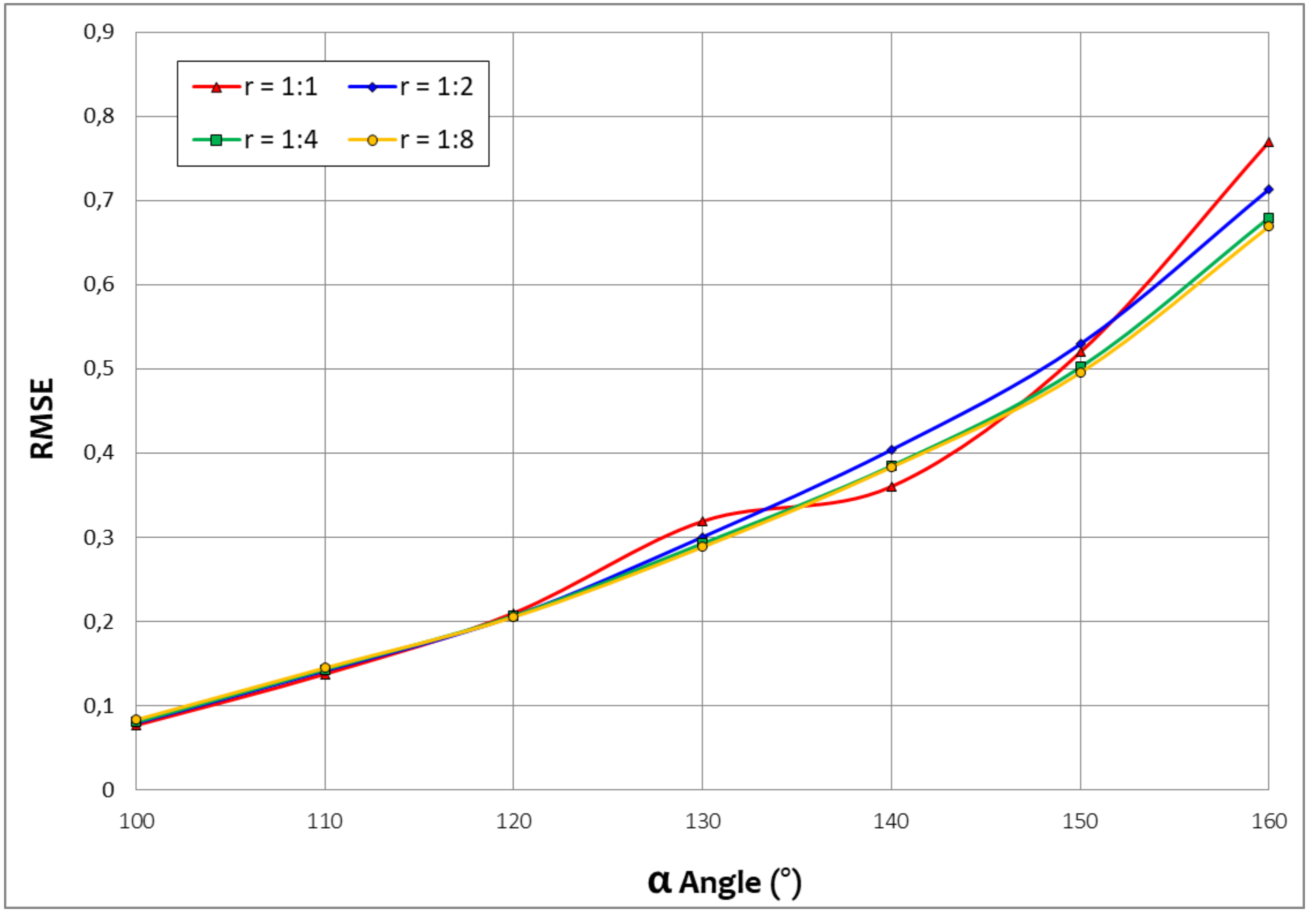


RESULTS

2. Evaluation of the relative ground structure for Non-orthogonal fractured system

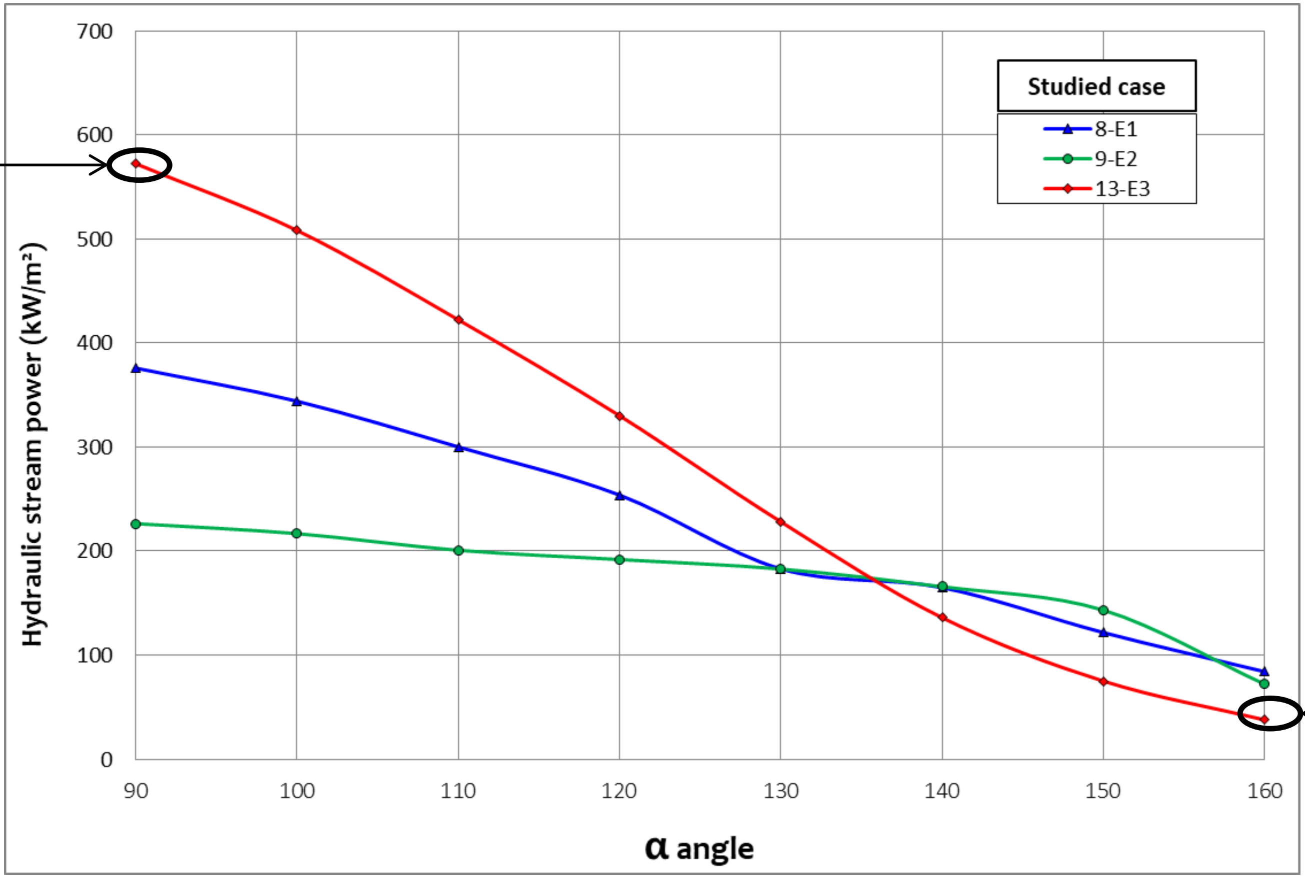
Root Mean Square Error ➡

$$RMSE = \left(\frac{1}{n} \sum_{i=1}^{n} \left(Js_{Kirsten} - Js_{Angle\,\alpha} \right)^2 \right)^{1/2}$$



RESULTS

2. Evaluation of the relative ground structure for Non-orthogonal fractured system



Data from Van-Shalkwyk et al. (1994)

Required hydraulic stream power = **572** kW/m²

Required hydraulic stream power = **38** kW/m²

FUTURE STEP

Numerical evaluation of the role and the impact of geomechanical characteristics

Index	Conditions	Characteristics
eGSI [1]	Intact rock	*Uniaxial Compressive Strength*
	Joints conditions	*RQD*
		Joint Spacing
		Persistence
		Aperture
		Roughness
		Infilling gouge
		Weathering
	Block conditions	*Shape*
		Dipping
		Orientation
RMEI	Joints conditions	*Number of joints set*
		Dipping
		Orientation
		Roughness
		Uniaxial Compressive Strength
		Aperture
		Joint Spacing
	Block conditions	*Shape*
	Spillway flowing conditions	*Protrusion of joints*
		Opening of defects
		Weathering

1: The characteristics of eGSI have been specified on the basis of the RMR system

System	Characteristics															
	Intact Rock				Joints								Others			
	UCS	PLS	SH	TS	JN	JV	JR	JA	JO	JS	JC	JG	RQD	W	SV	A
Franklin et al. (1971)	X	X								X				X		
Weaver (1975)	X								X	X	X	X		X	X	
Read et al. (1980)		X							X	X	X	X		X	X	
Kirsten (1982)	X				X		X	X	X	X			X			
Scoble & Muftuoglu (1984)	X	X								X				X		
Singh et al. (1987)		X		X						X				X	X	X
Smith (1986)	X								X	X	X	X				
Scoble et al. (1987)		X				X			X	X				X		
Karpuz (1990)	X		X							X				X	X	
MacGregor et al. (1994)	X				X		X	X	X	X	X	X		X	X	
Hadjigeorgiou & Poulin (1998)		X				X			X	X			X	X		

UCS: *Uniaxial Compressive Strength*
PLS: *Point Load Strength*
SH: *Schmidt Hammer*
TS: *Tensile Strength*
JN: *Number of Joints sets*
JV: *Volumetric Joint Count*
JR: *Joint Roughness*
JA: *Joint Alteration*
JO: *Joint Orientation*
JS: *Joint Spacing*
JC: *Joint Continuity*
JG: *Joint Gouge*
RQD : Rock Quality Designation
W: *Weathering*
SV: *Seismic Velocity*
A: *Abrasivity*

CONCLUSION

Our work to improve the geomechanical knowledge may give a better assessment of the hydraulic erodibility of rock

Thank you for your attention !

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UQAC

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